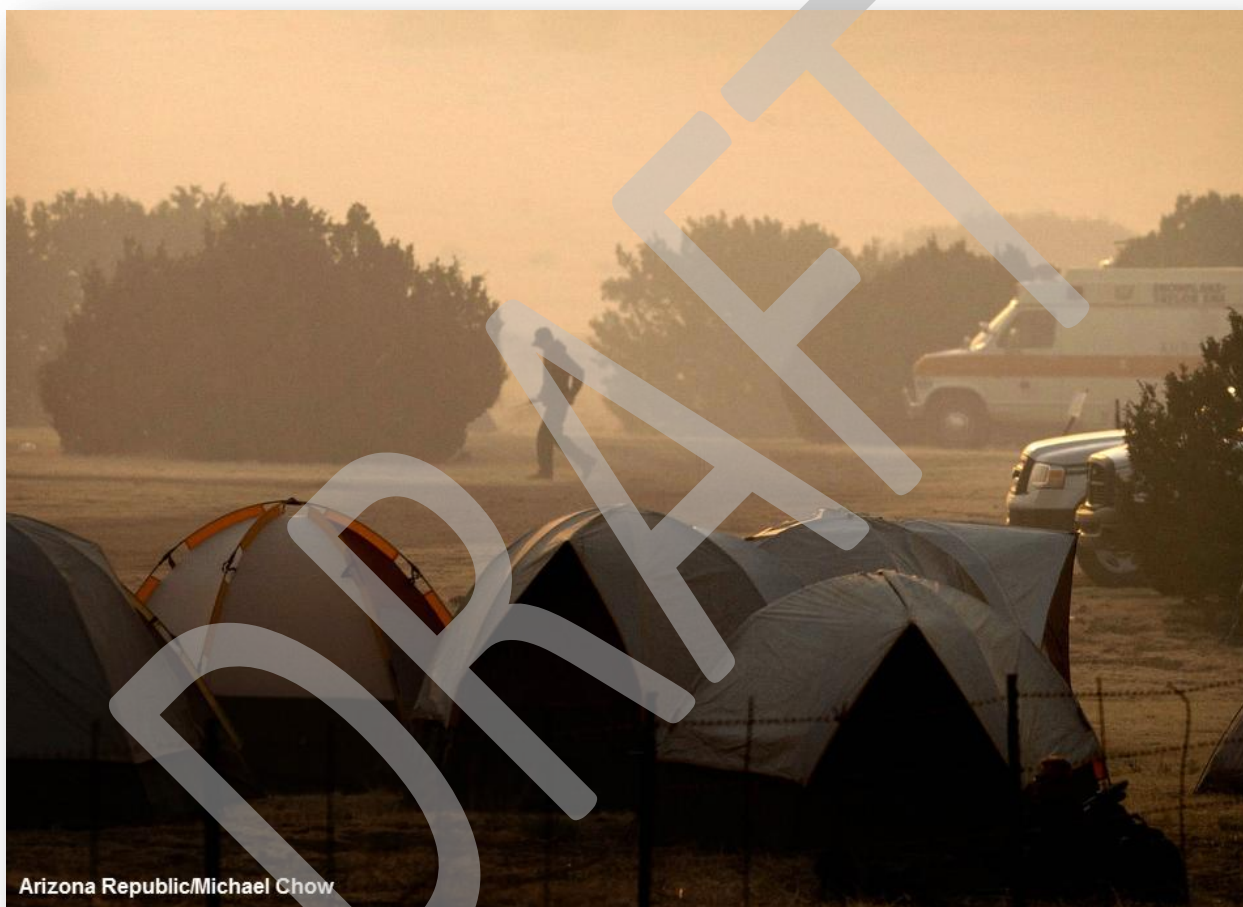


# Wildland Fire Personnel Smoke Exposure Guidebook

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Produced by the National Wildfire Coordinating Group Smoke Committee's Training Subcommittee and the University of Idaho (Version 3-2014)

University of Idaho  
College of Natural Resources



## Introduction

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Working on a wildland fire incident you are responsible for the safety of yourself and those around you. Smoke inhalation can jeopardize this safety by directly impairing your decision-making abilities. If your health is impaired your judgment and decision making skills may also be impaired. This condition can put those around you at risk.

This guidebook is divided into 3 parts:

- **Smoke Constituents& Symptoms** - What is in wildland fire smoke
- **Personnel Risk** - What positions are frequently at risk from wildland fire smoke exposure
- **Mitigating Exposure** – How to reduce or eliminate smoke exposure

Please note that this guidebook is a draft document and a work in progress. The authors feel the guidance information within will be useful to wildland fire personnel, however in the future content may be added, edited, and page numbers may change.

## Part I. Smoke Constituents - What is in wildland fire smoke

Work on the fireline does not always occur in smoke, and in many cases may take place in clean air. However, when the air is smoky the risks described herein are present. In this section we will describe constituents of smoke from the perspective of safety risks and performance impairment, as well as health risks. Short term and long term concerns will also be addressed. As gases in the smoke become attached to particulates they enter the airways and lungs causing further irritation and allowing some of these toxic gases to pass through the lungs to the bloodstream. Two aspects of greatest health concern in wildland fire smoke are particulate matter and carbon monoxide. Additional substances such as crystalline silica dust, while not present in smoke, can also pose health risks on the fireline. Below we describe each of these.

**Carbon Monoxide (CO)** is a natural byproduct of burning biomass. This gas is most highly concentrated in close proximity to the combustion source, or downwind from smoke sources. Base camps and spike camps are susceptible to downwind exposure, especially if they are located within a couple miles of the fire front, or if prolonged atmospheric inversion has prevented the smoke from dispersing. The further away from the combustion source, the less concentrated this gas becomes.

As CO is inhaled it attaches to hemoglobin (red blood cells) thereby reducing the oxygen carrying capacity of the blood. The CO laden blood cells, referred to as carboxyhemoglobin (COHb), transfer CO throughout the body in place of oxygen (Figure 1). This COHb is an indicator of the percentage of CO in the bloodstream, and reflects an individual's physiological response to CO. Increasing levels of CO exposure result in increasing COHb concentrations and increasingly severe consequences as displayed in the table below.

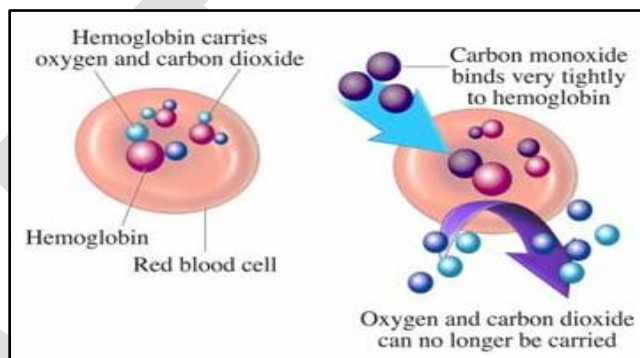


Figure 1. Illustration of carboxyhemoglobin. Binding sites on the red blood cell that would normally be occupied by oxygen are occupied by carbon monoxide.

CO in atmosphere (ppm)	COHb in blood (%)	Signs and Symptoms
10	2	Asymptomatic
70	10	No appreciable effect, except shortness of breath on vigorous exertion; possible tightness across the forehead;
120	20	Shortness of breath on moderate exertion; occasional headache with throbbing in temples
220	30	Headache; irritable; easily fatigued; judgment disturbed; possible dizziness; dimness of vision.
350-520	40-50	Headache, confusion; collapse; fainting on exertion
800-1220	60-70	Unconsciousness; intermittent convulsion; respiratory failure, death if exposure is long continued
1950	80	Rapidly fatal



**COHb levels can be halved with 4 hours of recovery time in clean air**

Short term exposure to CO and other irritants in wildfire smoke result in consequences that all firefighters are familiar with including: eye irritation, upper respiratory irritation, headaches, nausea and fatigue. As less oxygen is available the heart works harder to compensate. **Oxygen depletion leads to fatigue, headaches and potential loss of clarity in thinking. Long durations or very high CO exposure can result in loss of consciousness and ultimately death.** Some of the other irritants in wildland smoke affect the same organs and produce similar responses in the body. This causes a synergistic effect so at low levels of exposure to multiple irritants it may be similar to high exposure to CO.



**As high levels of CO are inhaled clouding thinking and impairing judgment, you become less capable of carrying out the 10 standard fire orders, jeopardizing your safety and the safety of your crew and those around you. Under these conditions it will be more difficult to:**

- "Be alert. Keep calm"
- "Think clearly"
- "Act decisively"
- "Give clear instructions and be sure they are understood"
- "Fight fire aggressively, having provided for safety first."

### **Aldehydes - Formaldehyde and Acrolein**

Formaldehyde and acrolein are the two most potent aldehydes in wildland fire smoke that create adverse health impacts. Short term effects include eye, nose and throat irritation, depression of breathing rates, and temporary paralysis of cilia (microscopic hairs lining the respiratory tract which help to remove dust and bacteria). The eyes and mucous membranes are especially sensitive to, and irritated by, acrolein (Kane and Alarie 1977). Chronic exposure to formaldehyde is associated with nasal cancer (U.S. Department of Labor, Occupational Safety and Health Administration 1987).

### **Nitrogen Oxides (NO<sub>x</sub>)**

Nitrogen dioxide (NO<sub>2</sub>) is one of the pollutants regulated by the EPA for human health impacts. Nitrogen oxides, including NO<sub>2</sub> are emitted as biomass burns. NO<sub>x</sub> can irritate the airways when it is inhaled and it is also a key component of ozone formation.

### **Ozone (O<sub>3</sub>)**

Ozone is another pollutant regulated by EPA and associated with human health effects including inflammation of the airways, shortness of breath, and

reduced lung function. The formation of ozone occurs when nitrogen oxides and volatile organic compounds (VOCs) from smoke react in the presence of sunlight. This reaction generally occurs away from the fireline, potentially causing impacts downwind. Ozone can be present regardless of fire emissions and is often more an issue in summer and downwind of urban areas.



**Particulate Matter** — Numerous studies have demonstrated that particulate matter can negatively impact human health both in the short and long term. Particulate matter can range in size from 100 microns in diameter to nearly the size of a few atoms (Figure 2). The potential of particles to cause harm depends on their chemical composition and their size. The smaller particles, PM 4.0 or less, pose the greatest health risk as they can be drawn [deep into the lungs](#) upon inhalation and are more difficult for the lungs to expel (Figure 3).

Fine particles cause upper and lower airway distress. This irritation results in coughing, sore throat, and diminished breathing. Prolonged exposure to particulate matter can also reduce a firefighter's work capacity. Irritation of the lungs and respiratory system and shortness of breath may make it increasingly difficult for individuals to sustain their optimum performance. Wildland firefighters typically maintain high physical standards so the consequences may not be severe, however exposure to particulate matter may eventually compromise their ability to maintain these standards. Given recovery time in clear air, your body will expel these via coughing. Smaller particles take longer to expel, and **this process is impeded if you are constantly in smoky conditions where there is less clean air to allow your body to recover.**

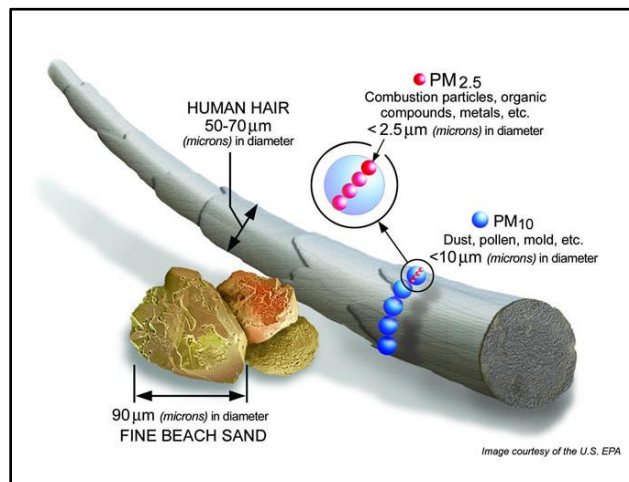


Figure 2. Particulate matter sizes compared with that of a human hair.

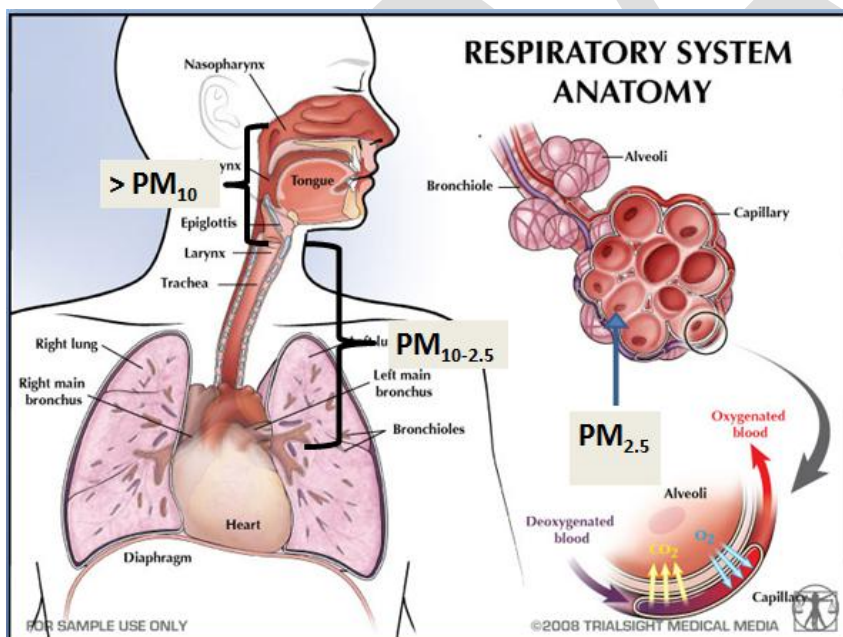


Figure 3. Larger particles are 'filtered' out by the respiratory system early on, while small particles can be inhaled deep into the lungs.

individuals, but there is evidence that chronic exposure can lead to hardening of the arteries (Naeher *et al.* 2007), and even an acute exposure may increase the risk of cardiac events among those with preexisting cardiovascular disease (Diaz 2012).

Health effects from PM may be short term, experienced over a few days, or longer term, such as throughout an incident, **resulting in reducing the body's capability to ward off infection and other pathogens leading to increased susceptibility to 'camp crud' and other ailments.** Firefighters can inhale large amounts of particulates from smoke which can remain in the lungs for a period of time, sometimes for months, following a fire or fire season.

Air pollution and public health research has confirmed an inflammatory effect in the lungs from small particles in the PM<sub>2.5</sub> range. Intermittent exposure to smoke may not pose a hazard to healthy



### Contributing factors

- **Heat stress** from vigorous work in high temperatures may compound smoke effects.
- **Harder work and higher altitude** are conditions which facilitate more rapid formation of COHb
- **Exposure to multiple pollutants** is worse than just one. Most studies focus on a single pollutant impacting the body, but in the case of wildland fire smoke, personnel are exposed to several pollutants concurrently which may compound and accelerate effects.
- **Physical condition** becomes a factor, especially considering smoke puts additional strain on the cardiovascular system. Personnel in arduous positions may be in better physical condition and at less risk for these issues, while non-arduous personnel are usually less physically fit and may have more baseline health issues which could be exacerbated by smoke.
- **Pre-existing high levels of pollution**, such as in areas with urban and industrial activities, compound pollution from wildland fire to create even greater concentrations of pollutants to which people can be exposed.
- **Nitrogen Oxides** can be elevated in these smoky conditions and combined with other pollutants have been found to increase the likelihood of ischemic stroke (Wellenius et al. Arch Intern Med, 2012).

**Note** Air quality standards for the general public are measured in PM<sub>2.5</sub>. However, occupation health standards consider a wider range of particle sizes, up to 4 µm(PM<sub>4</sub>), all of which can be drawn deep into the lungs. Smoke concentrations measured with a PM 2.5 sampler will be lower than those measured with the PM 4 sampler, but the concentrations would still be similar as the majority of smoke particulates are less than 0.6µm in diameter (Reinhardt and Ottmar, *in draft*)

### Other exposure hazards

Aside from PM and CO, there are less common exposure hazards depending on your location and the incident. These include crystalline silica, asbestos, oil and gas field emissions and around mine tailings.

**Crystalline Silica (SiO<sub>2</sub>):** Silica is a common component of soil, sand, and granite. Quartz, cristobalite, and tridymite are crystalline forms of silica that can occur as small, jagged particles. High exposure to crystalline silica has been linked to silicosis, a respiratory disease. Silica can be inhaled when the soil is disturbed during mop-up activities, traversing dry trails and dirt roads, and disturbing dust in burned areas.

**Asbestos:** Asbestos exposure lays the groundwork for the human body to develop mesothelioma cancer years after the exposure. A large number of homes and commercial buildings constructed prior to the 1980s were built with asbestos materials. Those products are considered safe as long as they are contained. But once ripped, broken, burned, blown or washed away, the products become a possible health hazard. Materials of particular concern related to asbestos are insulation, roof materials, drywall, ceiling tiles, flooring and asphalt. Wildland fire personnel may encounter naturally occurring asbestos dust in areas where the material was once mined or transported. In these areas a job hazard analysis should be created if one does not already exist.

## Part II. Personnel Risk - Positions and Tasks frequently at risk from wildland fire smoke exposure

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Safety risks are not only posed to those directly fighting the fire. Overhead, support staff and base camp personnel are also affected by fine particles and smoke. In addition, health screening standards are different for firefighters than for support staff, resulting in situations where personnel may occupy a wide range of health, fitness, susceptibility to smoke, and physiological responses to exposure.

Research on the exposure of wildland fire personnel to pollutants is ongoing. In 2012 the NWCG set interim exposure limits for wildland fire personnel (NWCG 2012). Research was requested to evaluate the exposure to smoke of various personnel positions for a typical wildland fire shift (13 hours)(Broyles 2013). Here are some of the results reported:

- The NWCG recommended shift occupational exposure limit for CO of 16 parts per million which was exceeded (95<sup>th</sup> percentile upper confidence limit estimate) by 11% by wildfire personnel, 9% by prescribed fire personnel, and 3% for initial attack personnel (Broyles 2013).
- When the highest 5-minute average CO levels were compared, wildfire personnel experienced the highest levels (933 ppm), followed by prescribed fire personnel (271 ppm) (Broyles 2013).
- Location in relation to the fire is important - Exposure to smoky conditions tended to occur during direct attack when digging fireline adjacent to an active fire, and mobile attack such as manning a fire hose in a slowly advancing vehicle (Reinhardt and Ottmar 2004)

### Other observations from the field

- During intense burning the smoke may be lofted up, while a reduction in heated air during less active periods may leave smoke closer to the ground

**Discussion Question:** What positions have you been assigned in which smoke exposure was high? Was there an opportunity to mitigate for this circumstance?

### Part III. Mitigating Exposure – How to reduce or eliminate smoke exposure

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It is important to note that smoke is just one of the potential risks faced by wildland firefighters. When instituting these recommendations it is important to evaluate and balance all the risks associated with the operational objective. There are several actions that can be taken to minimize smoke exposure, thereby minimizing these health impacts, especially among mop-up and holding positions, which data indicate receive the highest exposure levels. Those using equipment which generates exhaust, such as sawyers, dozer operators, and pump operators, also experience increased CO exposure due to their machinery.

#### **For Arduous positions**

Exposure to smoke and carbon monoxide can be mitigated by action to avoid exposure, limit exposure, recognize impairment, monitor exposure, and facilitate recovery.

#### **Avoid Exposure**

- Use time and patience to put the fire out i.e. allow secured areas to burn out, rely on burn-up instead of mop-up, and use dozers or other mechanical equipment to spread out burn piles
- In heavy smoke conditions consider establishing control lines where conditions allow for less smoke exposure to firefighters, even if more acreage is burned
- Use equipment instead of people when possible in holding areas (sprinklers, retardant, foam, etc).

#### **Limit Exposure**

- Minimize mop-up when possible, use alternative means with less exposure
- Established mop-up standards that meet true containment objectives to minimize exposing firefighters unduly to smoke hazards.
- Adjust operation periods on mop-up to avoid inversion periods
- Minimize snag falling as long as all other safety concerns are mitigated
- When possible, select strategy and tactics that minimize worker exposure (indirect attack).

#### **Recognize Risks & Impairment**

- Expect higher CO concentrations in the following:
  - Near an active flame front and during smoldering phase of combustion.
  - Working around heavy equipment, especially in ground support
  - Prolonged exposure to low to moderate smoke level can increase CO overexposure
- Topographic features that concentrate smoke (head of canyon, ravines, saddles or passes, depressions or basins).
- Working ground fires where organic soils (peat) are present have been documented for high release of CO, PM<sub>2.5</sub> and other pollutants.
- When working in areas of known high CO concentrations or PM<sub>2.5</sub> set up monitoring protocol under the auspices of the Safety Officer, Medical Unit and / or Air Resource Advisor.
- Restrict workers from operating a vehicle if they display the symptoms or behavior associated with carbon monoxide exposure.
- Personnel who display the symptoms of abnormal behavior should be evaluated and determined fit for duty before their next work assignment.



### Monitoring Exposure - Personal monitoring

It is recommended that firefighters monitor their health and their coworkers. Be watchful for the symptoms of exposure and respond appropriately. **The best option is to move to clean air and reassess your situation.**

- The best and most reliable method to “monitor” smoke exposure is to use your body. In the same way firefighters use their senses to evaluate their environment and adjust tactics to remain safe, smoke exposure should be monitored as well. When firefighters hear snags fall or rocks begin to roll downhill they reevaluate their safety. When storm cells move into the area they adjust their tactics to protect themselves. The same risk management approach is recommended for high smoke exposure situations.
- When smoke is present firefighters and fireline leaders (Division Supervisors, Safety Officers, and overhead), ALL need to be attentive to the signs and symptoms of smoke exposure. Headaches, scratchy throats, tearing eyes may all be an indicator that the exposure is high and needs to be mitigated. Your body is the best indicator, these symptoms are telling you to reevaluate the situation and respond accordingly.
- Although there are many electronic monitors available to measure CO and other gases in wildland fire smoke, many of these are not suitable for the wildland fire environment. In order for these monitors to protect firefighters and provide accurate information they must meet specific criteria. In addition, they must be able to perform under severe environmental conditions, have radio frequency interference protection and not be compromised by other gases and particulates in smoke. These monitors are life-safety devices and require regular calibration and function tests to assure they are working properly. Infrastructure and training must be in place prior to using these devices.
- Technology is available to non-invasively measure blood-carbon monoxide levels (COHb). If high CO exposure symptoms are present or suspected, these devices may be useful to medical personnel however no established protocol has been developed for wildland fire. Current research by the Forest Service National Technology and Development Program has not found a good relationship in wildland firefighters over a shift between ambient carbon monoxide and these measurements of carbon monoxide in the blood. Therefore, this technology currently is not a valid method to measure wildfire smoke exposure.

### Facilitate Recovery

- Rotate personnel (fireline and base camp) out of heavy smoke areas
- Transfer workers to 'CO-free areas' when performance and safety are compromised by CO exposure symptoms or behavior
- Instruct personnel to take breaks in smoke-free or low-smoke areas, when possible.
- Encourage cigarette smokers to terminate or reduce smoking during fire assignment. Smoking significantly increases blood CO levels.



Figure 4. Rotating crews to areas with clean air is an effective means to avoid exposure and facilitate recovery time. Due to prevailing winds, crews on the eastern flank of the Grouse Fire in Yosemite National Park worked in clean air (*right*) while crews on the western flank (*left*) were continually working in smoky conditions. Photos courtesy of George Broyles, USFS.

### For Mop up

Evaluate Mop-Up standards, are we doing them because “that is what we have always done”. Minimize mop-up when possible. Understand the leader’s intent and control objectives stated for the operational period. Typically the goal of mop-up is to assure the fire will not escape the established firelines.

For Planners	For Crew
Adherence to the mop-up standards should always be designed to minimize exposure. Over extending mop-up increases exposure to inhalation risks as well as other risks inherent in mop-up such as falling snags but does not increase the security of the fireline.	Use water for mopping up when available; however use a low pressure stream to avoid making particulates and crystalline silica airborne. Allow areas to burn out without mopping up when safe to do so.

### For Holding Operations

For Planners	For Crew
<ul style="list-style-type: none"><li>• Rotate crews/individuals out of the smoke and into clear air</li><li>• Rotate lighters and holders</li><li>• Adjust tactics when possible to assure smoke moves into the fire rather than across the fireline</li></ul>	<ul style="list-style-type: none"><li>• Do not stand any closer to the fireline than necessary</li><li>• Adjust tactics when possible to assure smoke moves into the fire rather than across the fireline</li></ul>

### **For Base Camps**

Locate incident Base and Camp(s) in areas free of smoke and air pollution to maximize recovery from CO and other pollutant exposure. Such a location will facilitate meeting OSHA standards for fireline personnel. Topographic features that concentrate smoke (head of canyon, ravines, saddles or passes, depressions or basins) should be avoided if possible. If local knowledge indicates historic prevailing winds from the fire are towards the base camp, then that location should also be avoided if possible. Depending on the proximity and cause of the smoky conditions in base camp, CO may still be a concern if the camp is near the fire or prolonged inversions prevent air from mixing and clearing for long periods.

### **Planning and Monitoring**

- Include smoke hazards on the Incident Action Plan Safety Analysis, ICS-215A worksheet, at planning and briefing sessions, and adjust operations accordingly.
- Address smoke impacts in job hazard analysis/risk assessments.
- Particulate matter smoke monitoring kits for base camps and other locations are available in the national cache system, NFES 5840. These systems come with easy to follow directions and a video is available. Twenty kits can be ordered through Resource Ordering and Status System (ROSS).

If a base camp either becomes smoky or avoiding smoke is not possible for safe operations, then further mitigation and monitoring should be considered:

### **For Smoke Impacted Base & Spike Camps**

- Utilize spike camps as alternatives to impacted camps or periodically rotate crews to clean air areas.
- Utilize facilities with filtered air systems such as hotels or other public facilities, etc.
- Order clean air tents or trailers with HEPA filtration (priority of use based on exposure to fire fighters and at-risk support personnel).
- If the base camp is likely to be smoky for an extended period consider using health and fitness screened personnel (people not at greater risk from particles, NO<sub>2</sub>, ozone, or CO) as support personnel.
- Consider the use of masks (N-95) in camp as needed to reduce particulate inhalation. See Wildfire Smoke: A Guide for Public Health Officials, pgs. 17-21 for a discussion of proper selection and use of N-95 masks or other respiratory protection (Lipsett *et al.* 2013). Use of such masks should be assessed on an individual basis to insure no pre-existing conditions are further aggravated.
- Reduce vigorous activity levels in base camp.
- Exposure can also be the result of anthropogenic sources such as vehicles (exhaust & dust) and generators. Design camp layouts to provide adequate distance between these sources and sleeping and work areas.
- Address trends of respiratory illness rapidly and consider resting and rotating high exposure firefighters if they show symptoms of high smoke exposure (see symptoms listed above).
- If monitoring is conducted, post corresponding Air Quality Index values at the ICP/Base Camp. Consider posting CO threshold values and symptoms (Table above) at the ICP/Base Camp and consider discussion in briefings.

**Discussion Question:** What are some effective routes of communication to communicate this information to planners and crew-members in your unit?

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